Update on FAST RECYCLER STACKING

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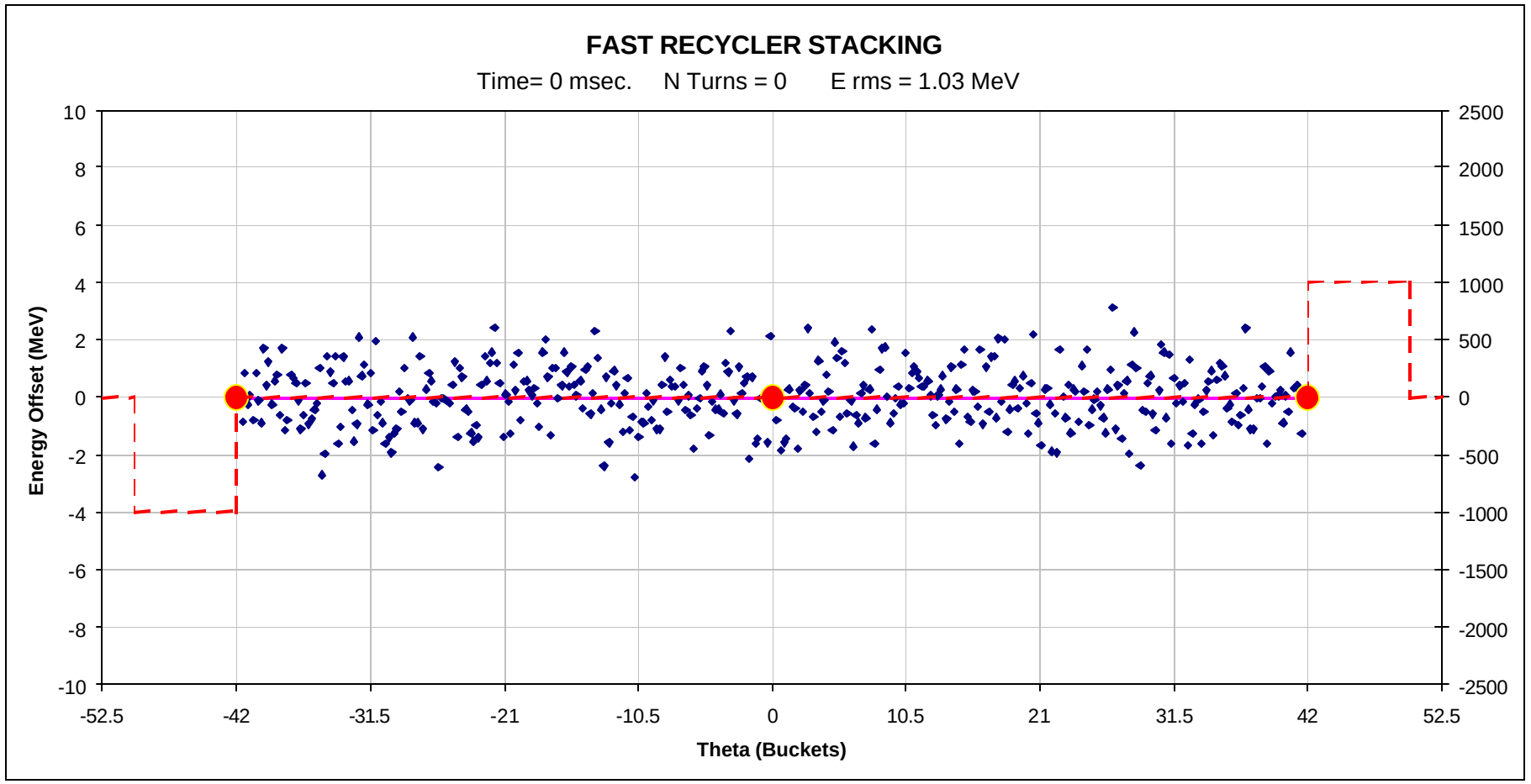
Fast Recycler Stacking

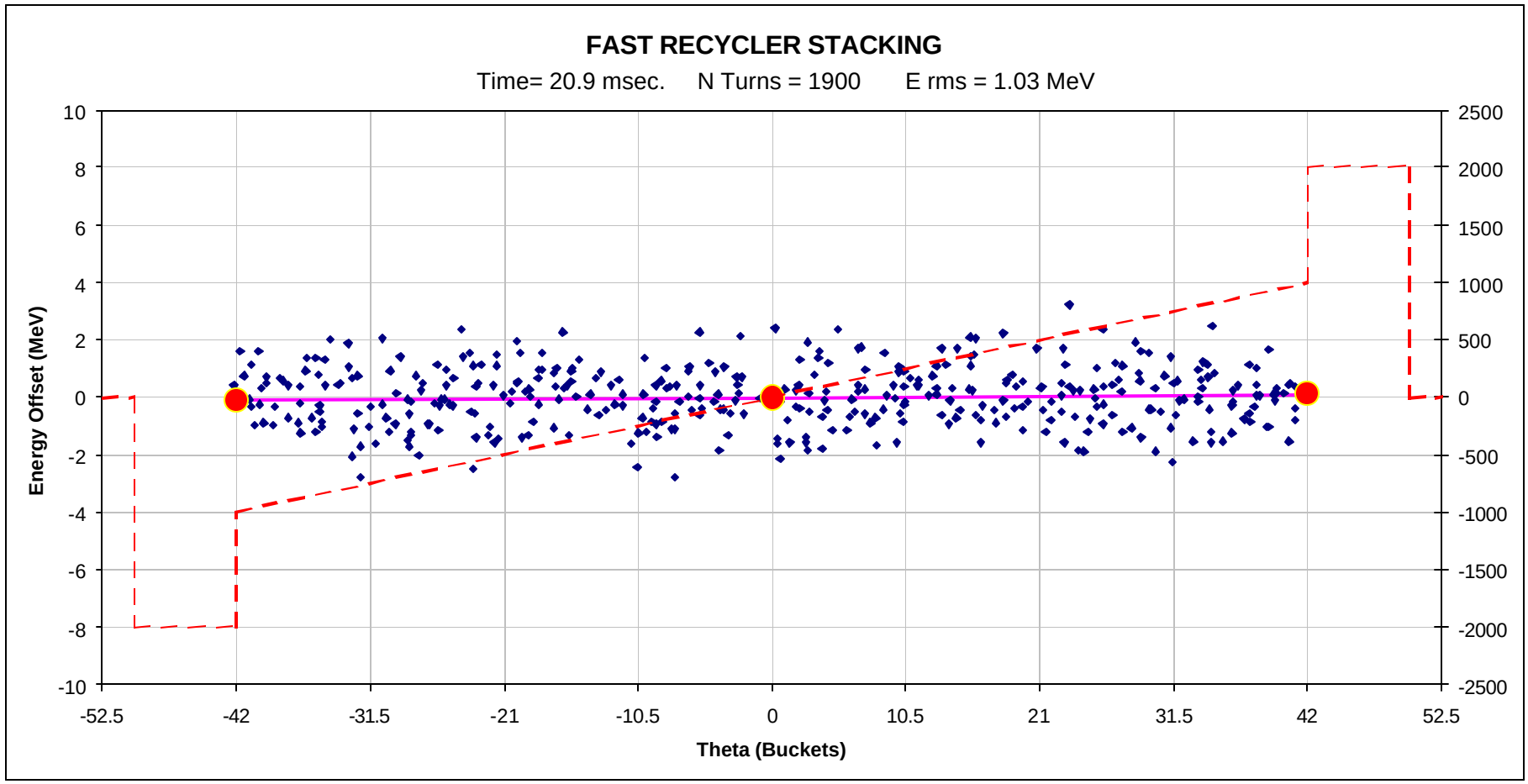
- Method of longitudinal stacking
  - Increases charge density in Booster batches by compressing them in time
  - *May* allow more batches stacked in MI
  - *Will* allow early tests of MI at higher beam currents
- Uses broadband “Arbitrary Waveform” RF system
  - Exists in RR; planned for longitudinal dampers in MI
- Advantages WRT Slip Stacking:
  - No emittance growth (in principle)
  - No problems with Beam Loading (debunched beams)

Fast Recycler Stacking: 1) Initial Condition



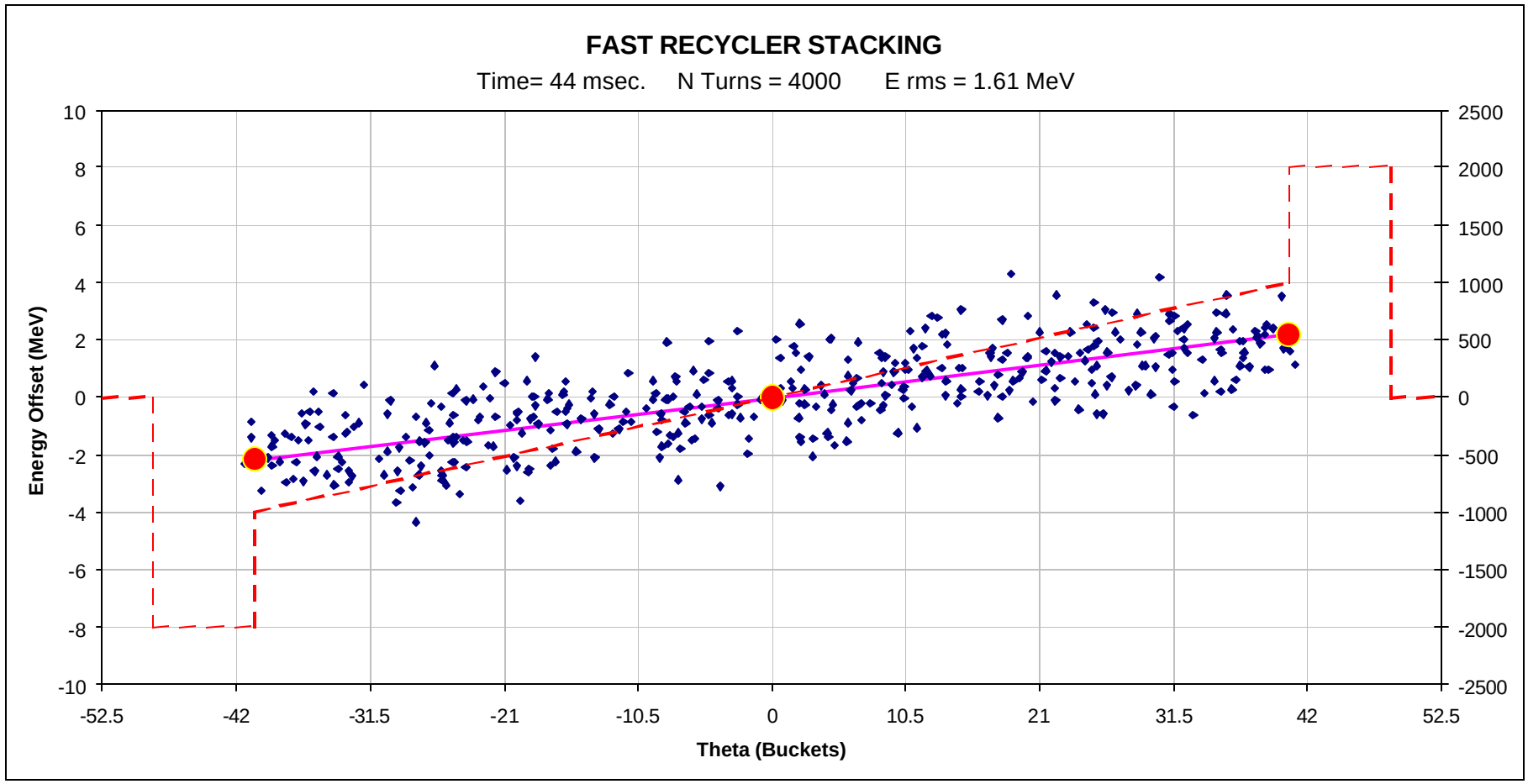
- **Debunched Batch Captured in Barrier Pulses**

Fast Recycler Stacking: 2) Ramped Waveform



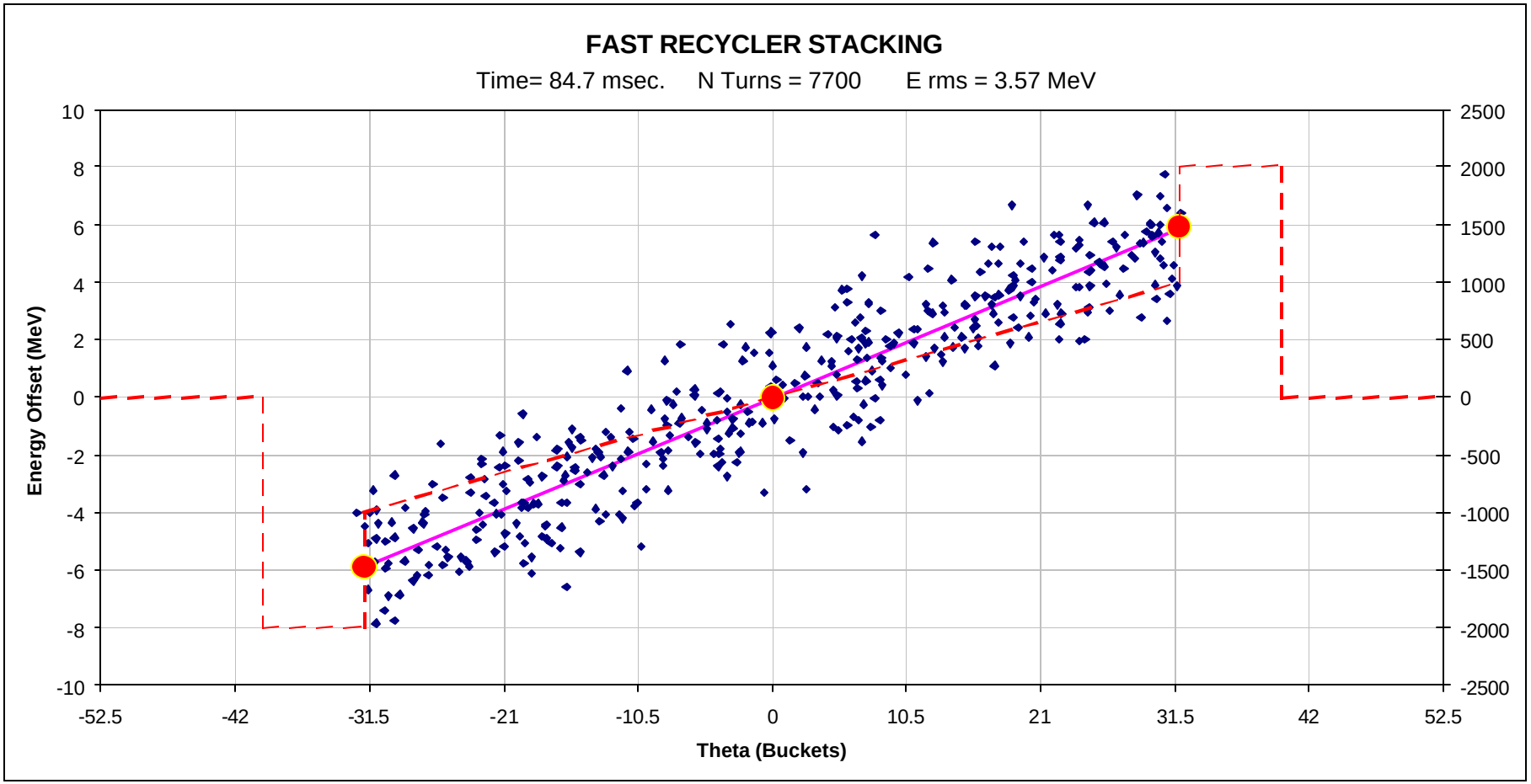
- Ramped waveform rotates phase space
- Barrier Pulses keep batch ends under control

Fast Recycler Stacking: 3) Phase Space Rotation



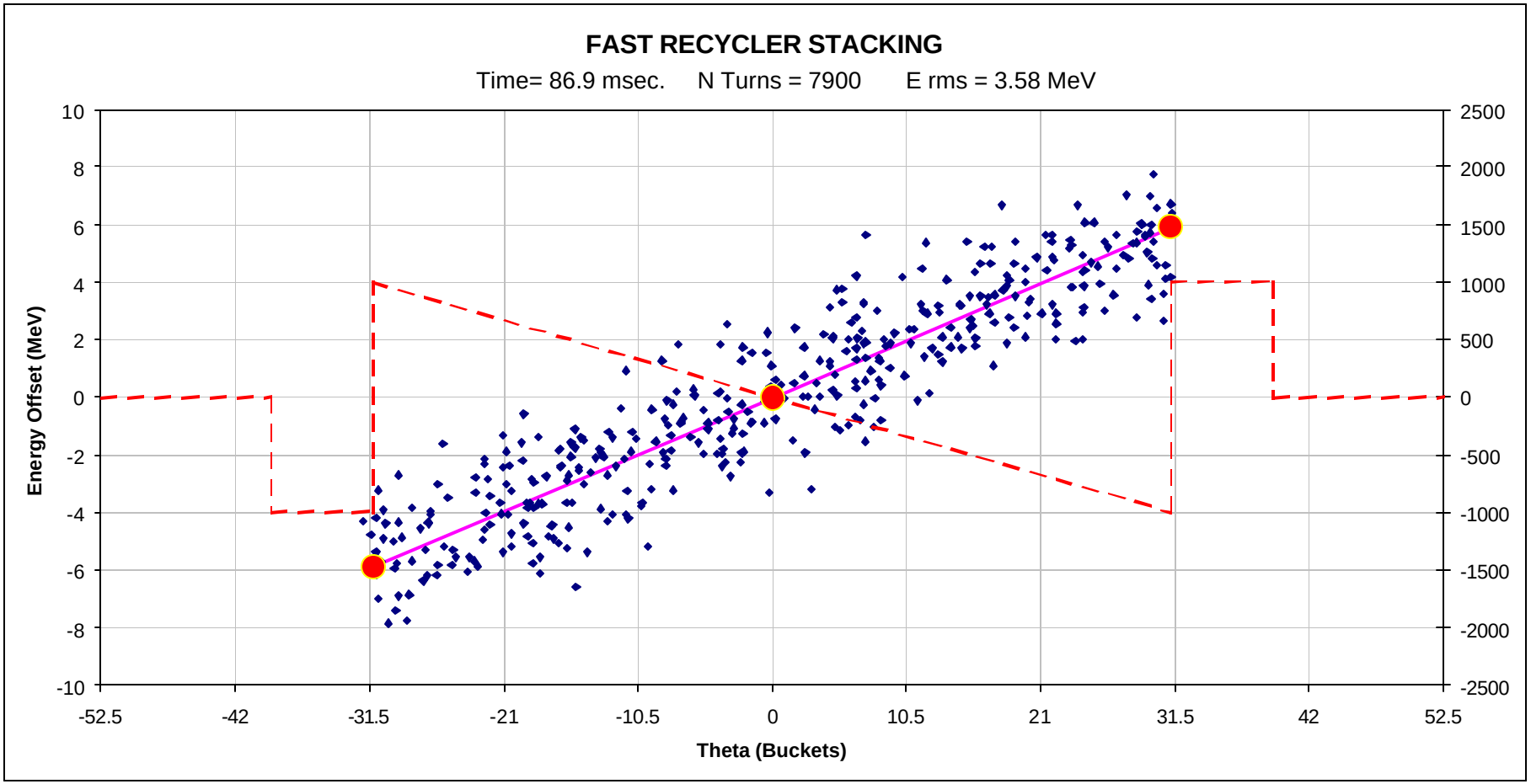
- Leading Particles Slowed Down and move inwards
- Trailing Particles Sped Up, also move inwards

Fast Recycler Stacking: 4) Halfway Done



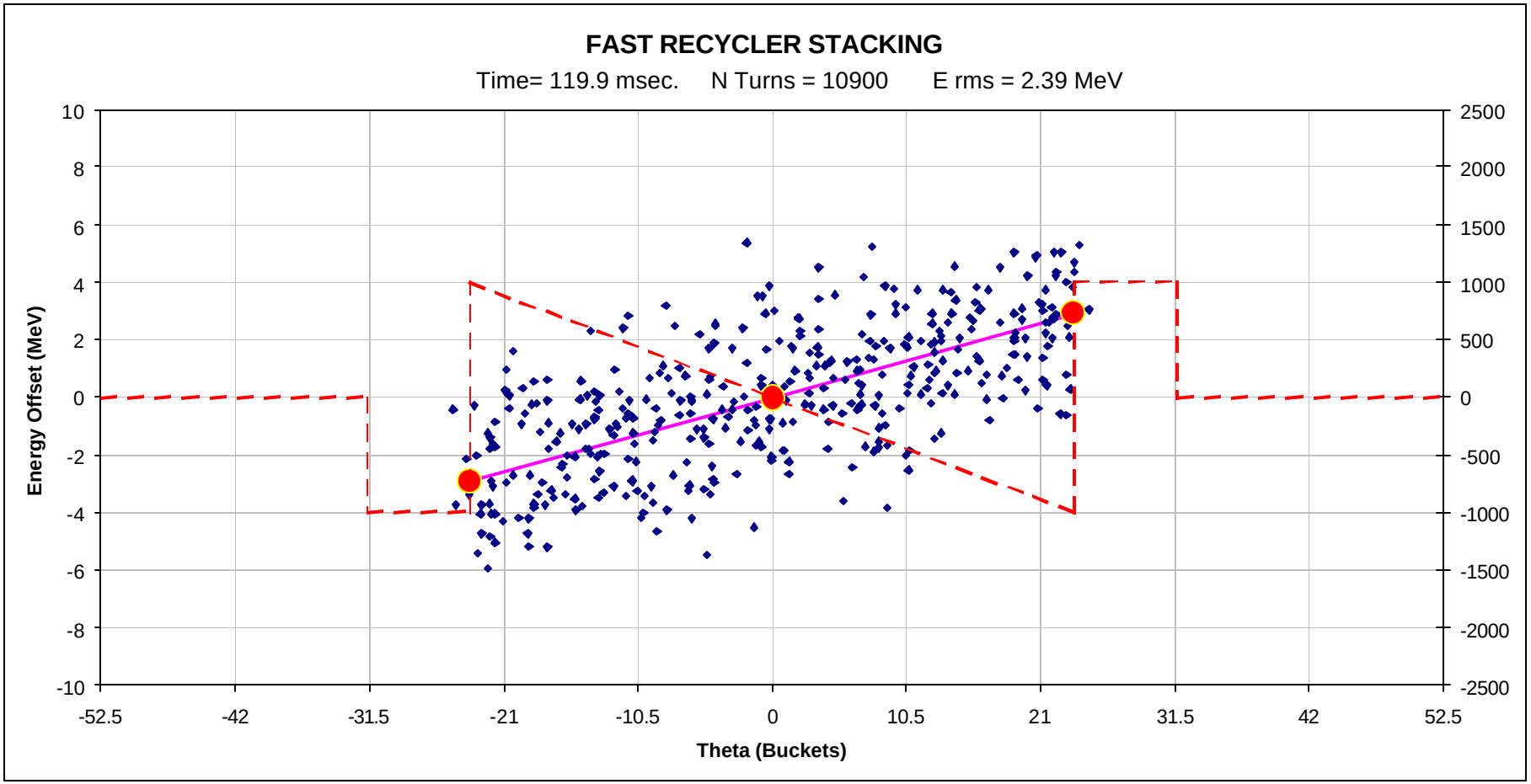
- Leading & Trailing particles are now halfway to their final destinations

Fast Recycler Stacking: 5) Reverse Ramp



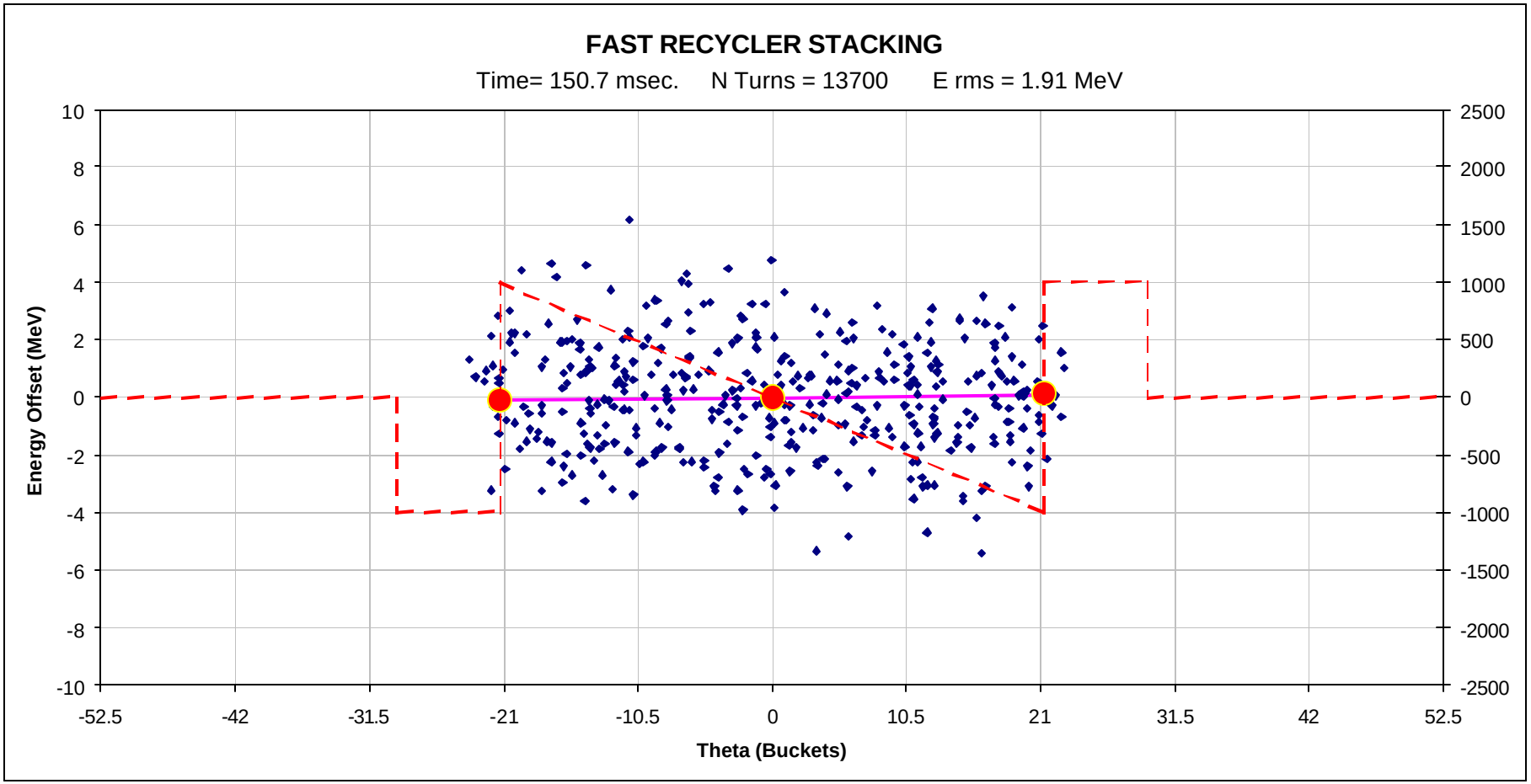
- Ramp Reversal needed to eliminate energy correlation at end of process

Fast Recycler Stacking: 5) Anti-Rotate



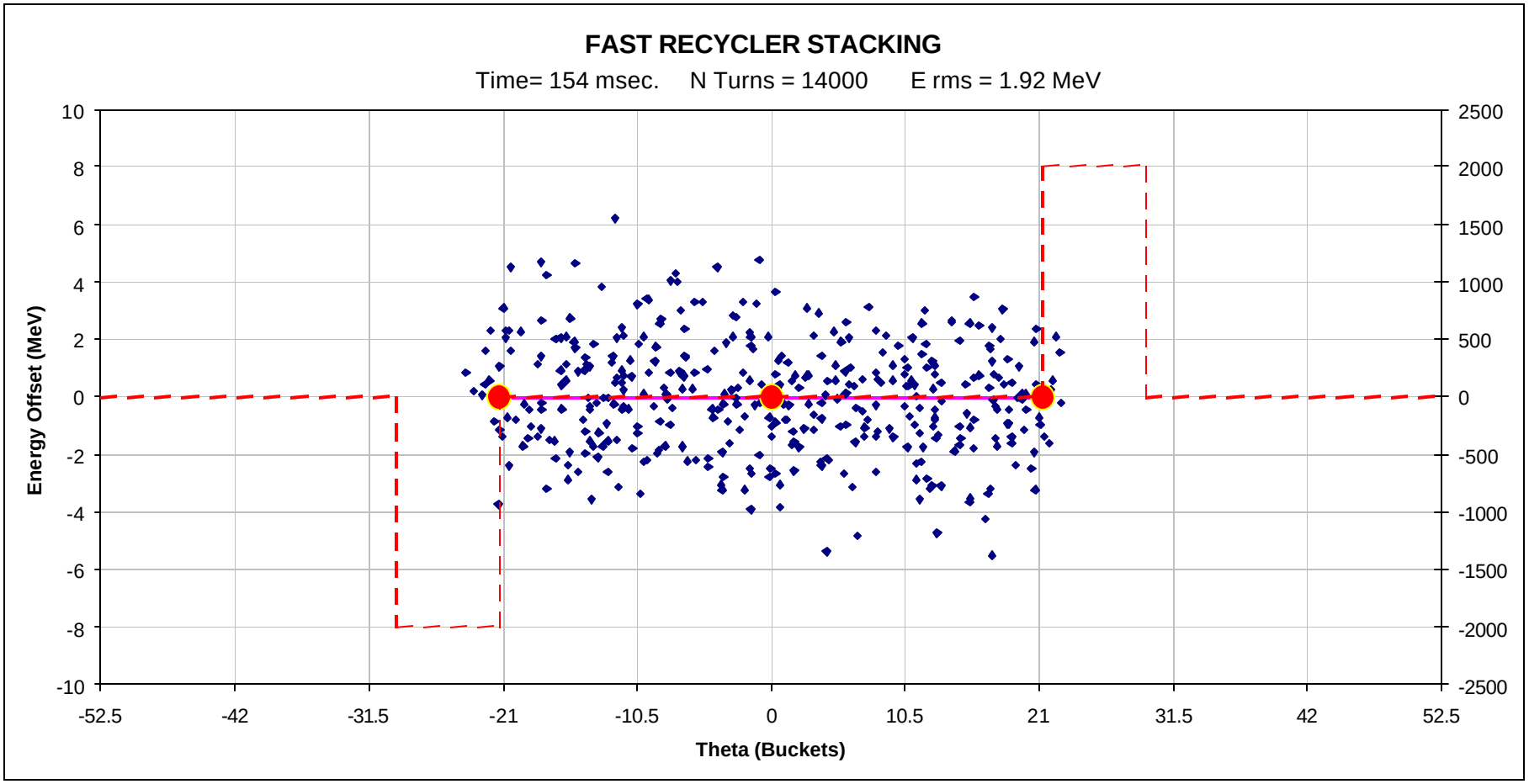
- Reversed ramp rotates phase space distribution back towards horizontal

Fast Recycler Stacking: 5) Anti-Rotation Completed



- Energy correlation removed at end of batch compression process

Fast Recycler Stacking: 6) Final State



- Final configuration: half the time spread, twice the energy spread ✍ no emittance growth

First Tests in Recycler (Nov. 20)

- Recycler already has 2000V Arbitrary Waveform RF system, with controls

- Recycler does not have extraneous cavities (2.5 MHz, 7.5 MHz and 53 MHz) which might resonate up ("beam loading") and destroy the beam RF structure.

1. Debunch beam in MI
2. Compress the beam in Recycler
3. Transfer back to MI
4. Rebunch and Accelerate (…not done)

Recycler Broadband RF Cavity

Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

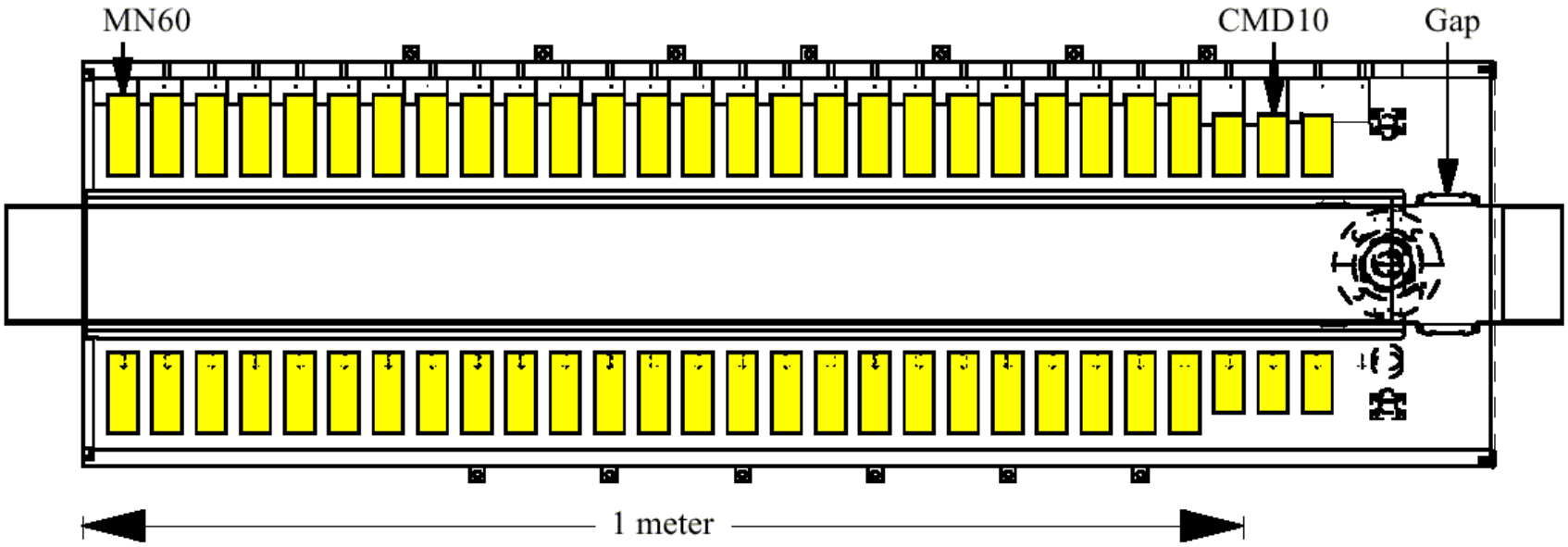


Figure 1: Schematic drawing of Recycler Wideband RF Cavity

Non-Resonant Cavity looks like 50-Ohm Load in parallel with a large Inductor

Wideband Power Amplifiers

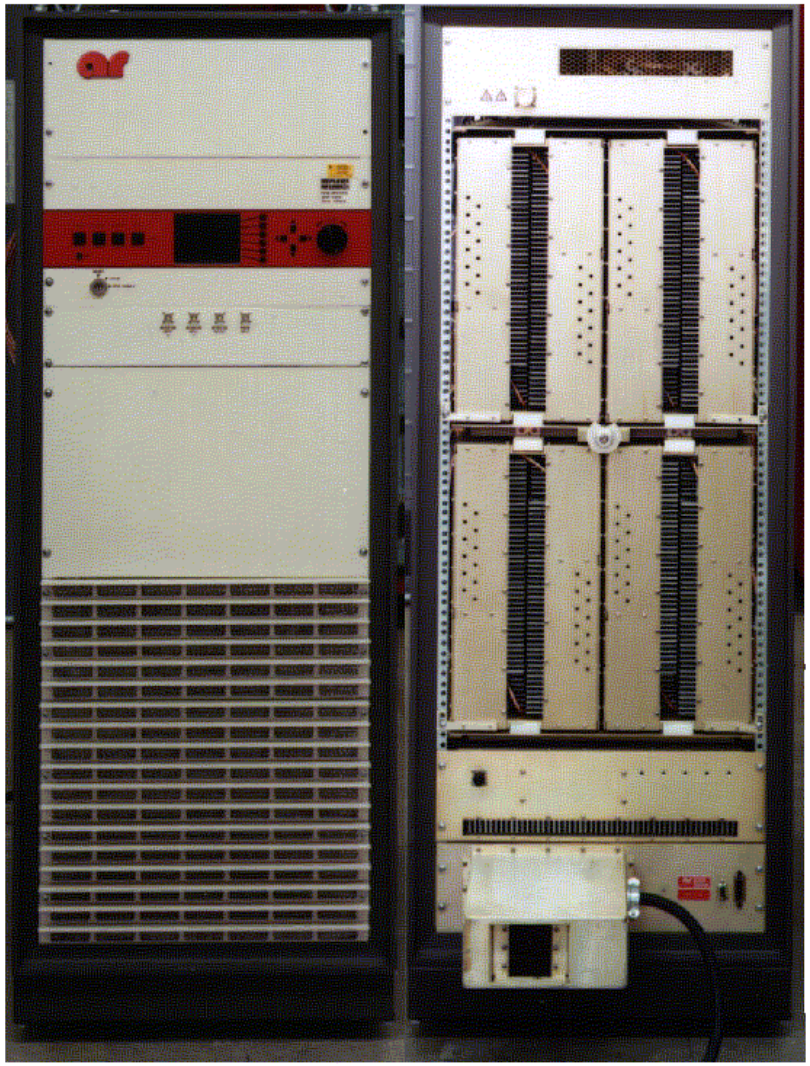
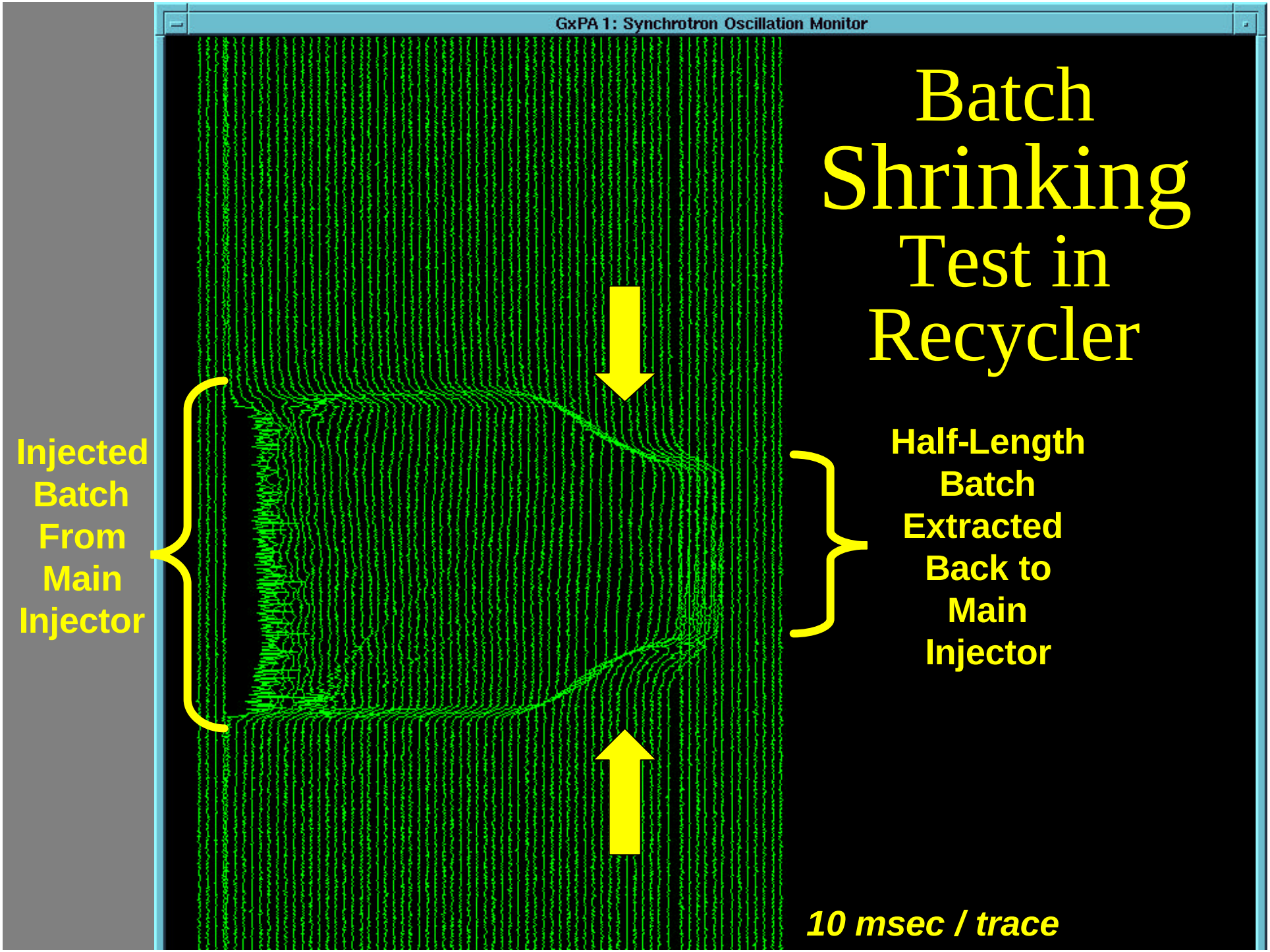
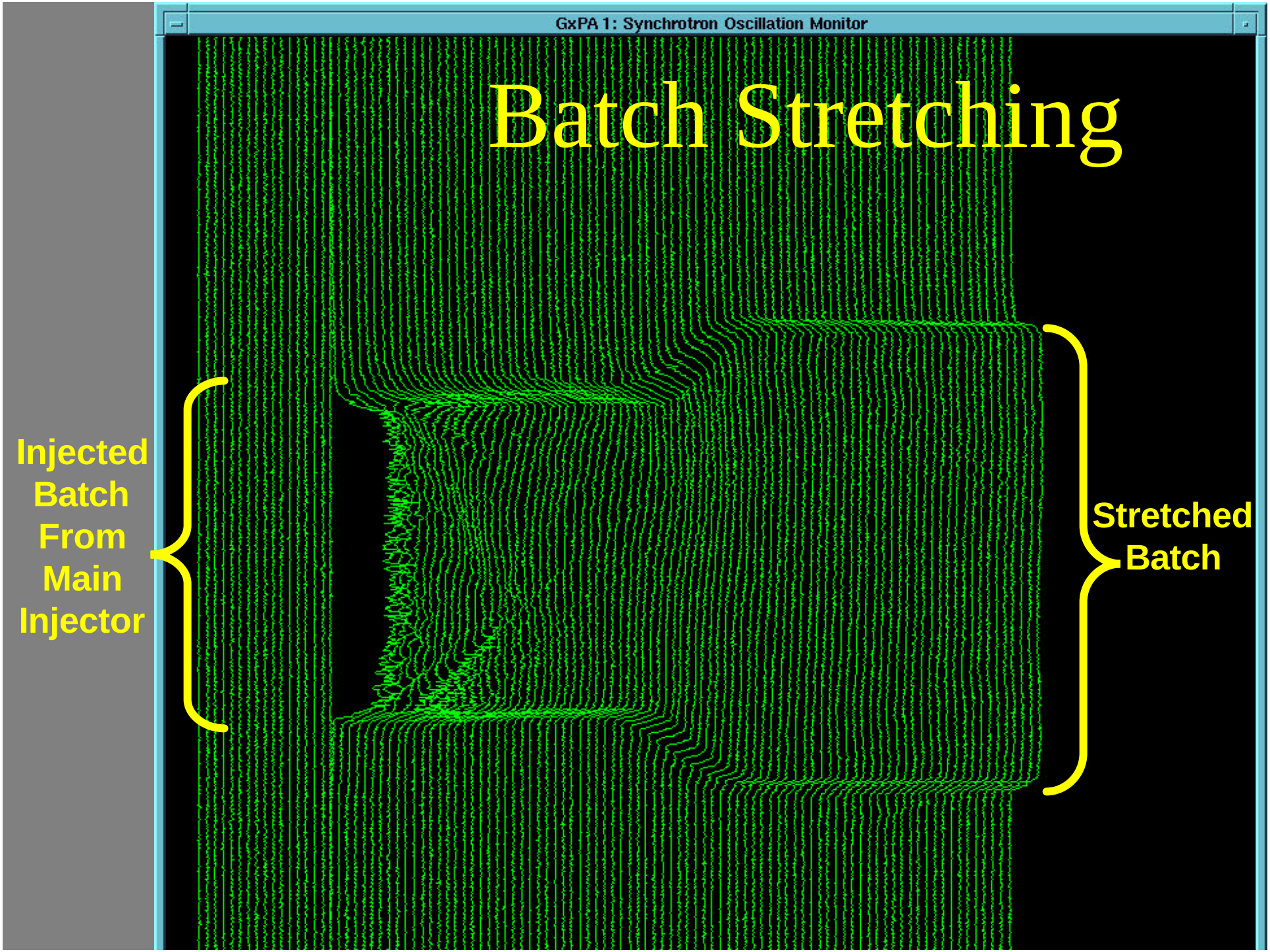
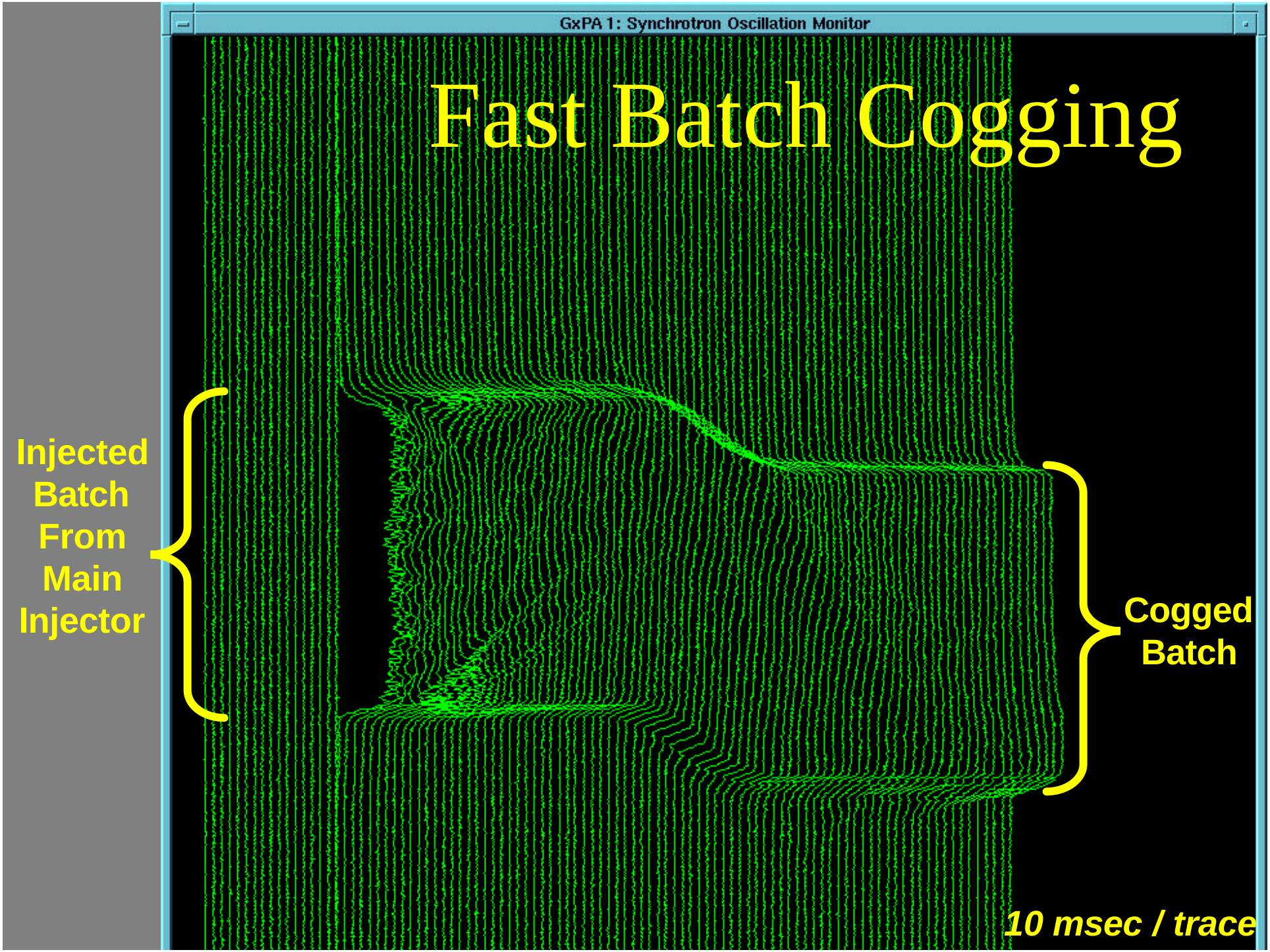


Figure 2: Front and Rear views of Amplifier Research model 3500A100.

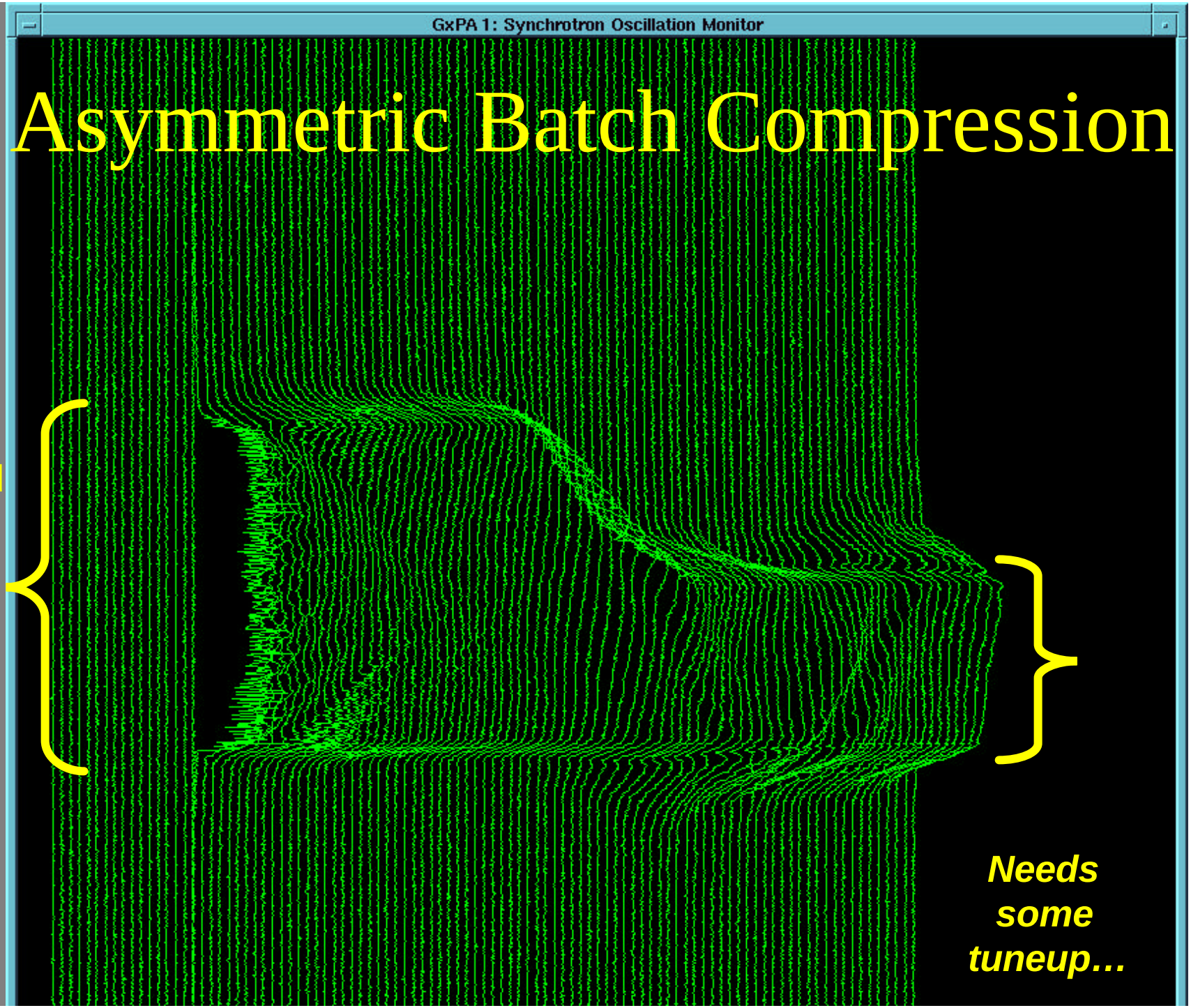
- Recycler has four of these amps, capable of generating +/-2000V or arbitrary waveform.
- Main Injector will soon buy 3 of these for longitudinal Dampers.


GxPA 1: Synchrotron Oscillation Monitor
Batch Shrinking Test in Recycler
Injected Batch From Main Injector
Half-Length Batch Extracted Back to Main Injector
10 msec / trace


GxPA 1: Synchrotron Oscillation Monitor
Batch Stretching
Injected Batch From Main Injector
Stretched Batch


GxPA 1: Synchrotron Oscillation Monitor
Fast Batch Cogging
Injected Batch From Main Injector
Cogged Batch
10 msec / trace

Asymmetric Batch Compression



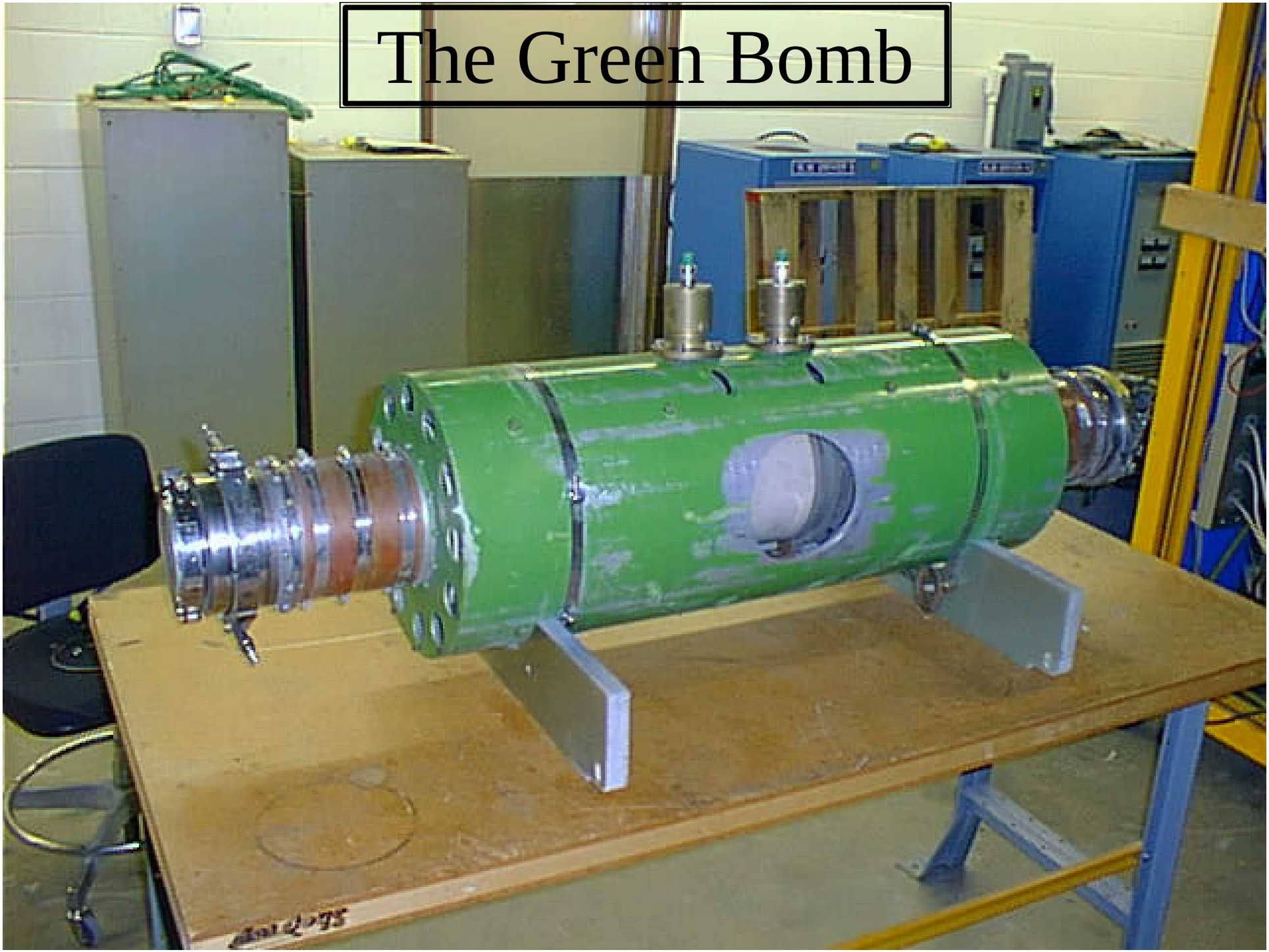
Remaining Tasks for RR Tests

- Understand Stacking Scientifically
  - Quantify emittance growth
  - Understand incoming beam properties
- Optimize Tuning
  - Push to higher currents
  - Compress Multiple Batches
  - Simulation work to recognize mis-tunings

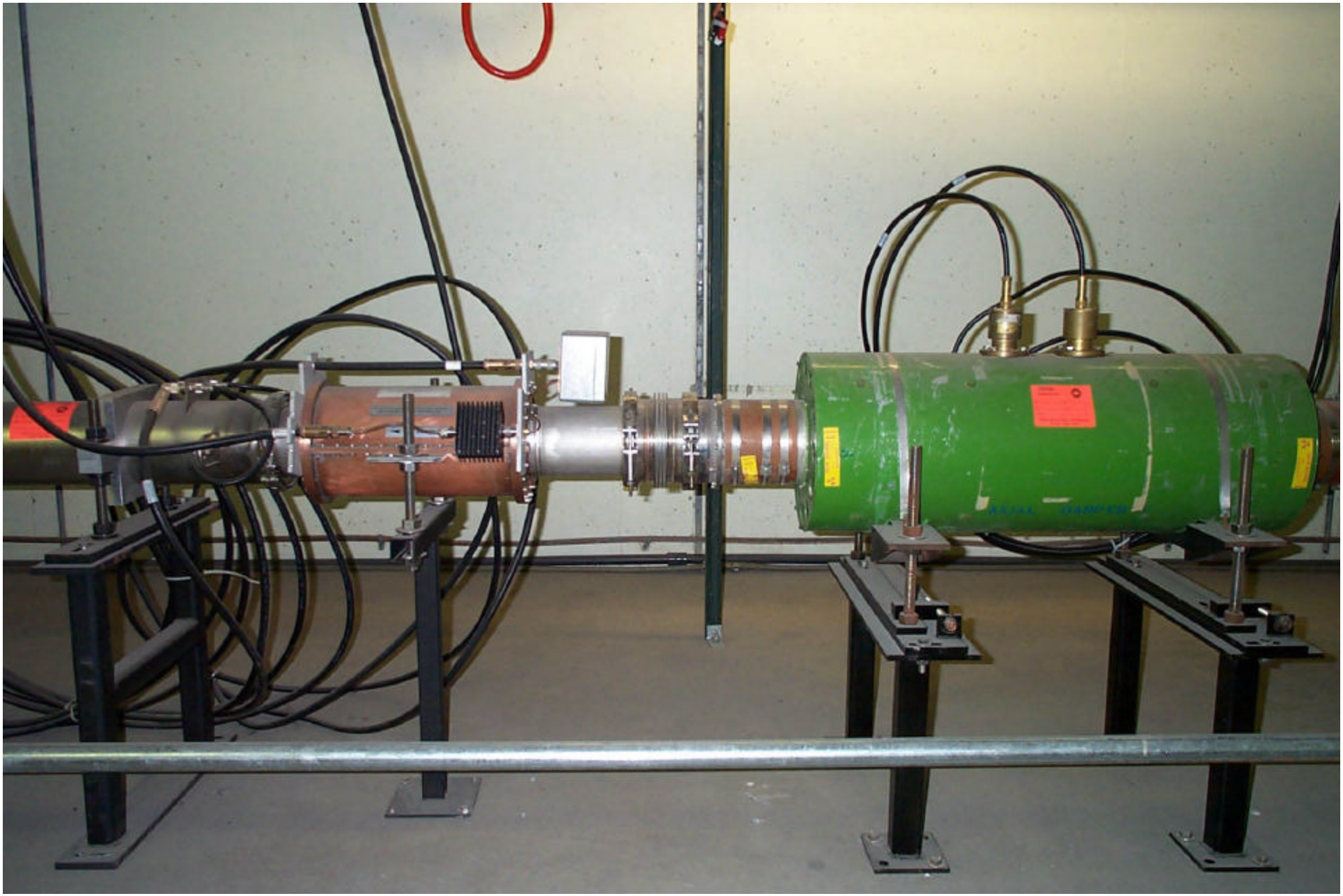
First Test in Main Injector (December 12)

- Patched together a 500 V barrier-bucket system in the Main Injector
  - "Green Bomb" (old broadband cavity in MI)
  - Spare Recycler Power Amplifier
  - Swiped arbitrary Waveform from Recycler
- Debunch beam in MI
  - Actually this is easier than transferring beam back and forth from the Recycler

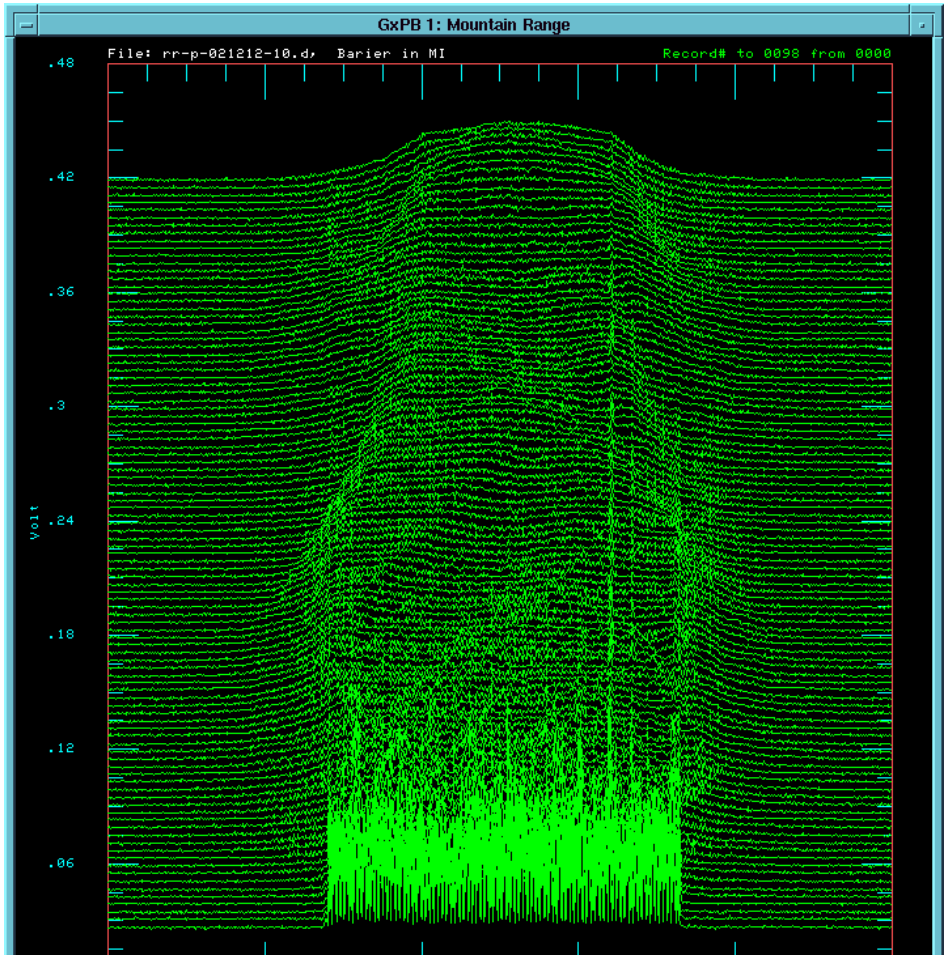
The Green Bomb



Green Bomb & Longitudinal Kicker in Tunnel



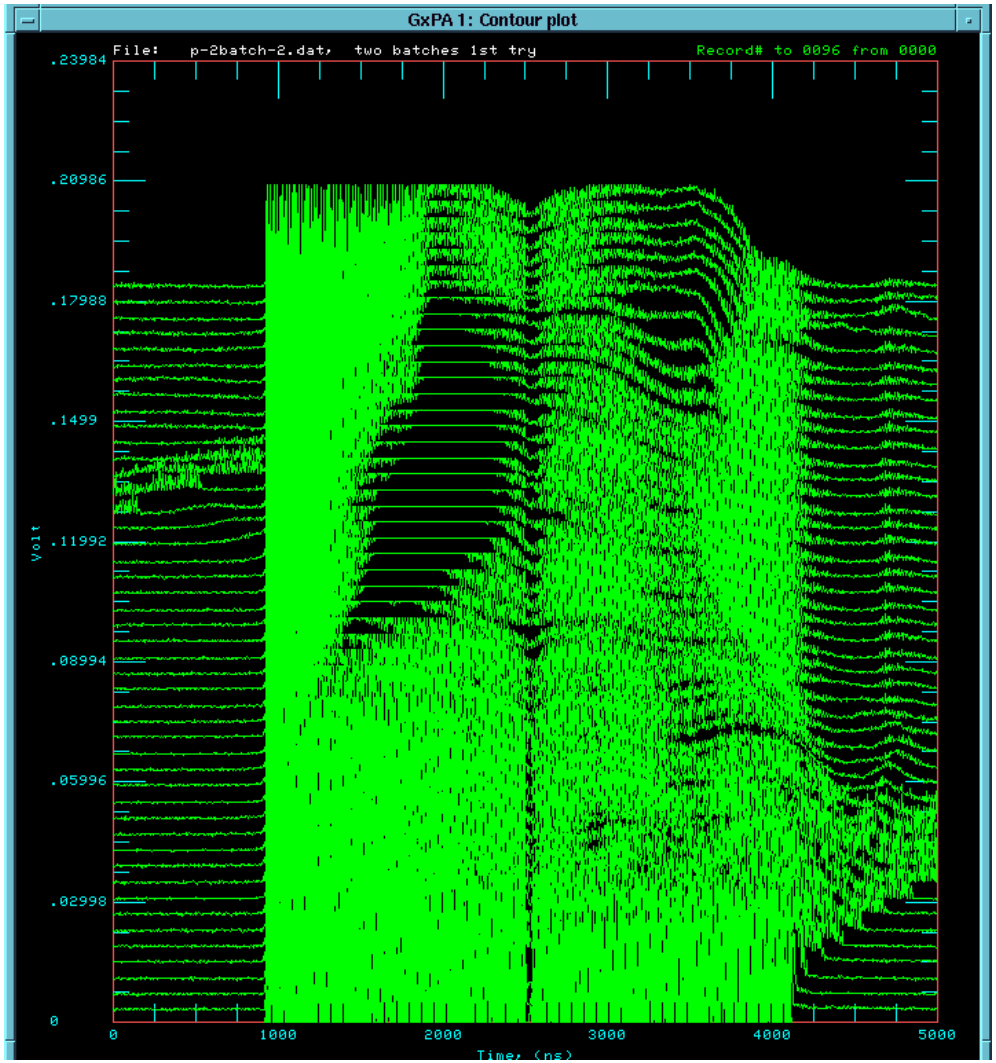
First Test in Main Injector



- Barrier Buckets Function
- Batch compression (sort of) works

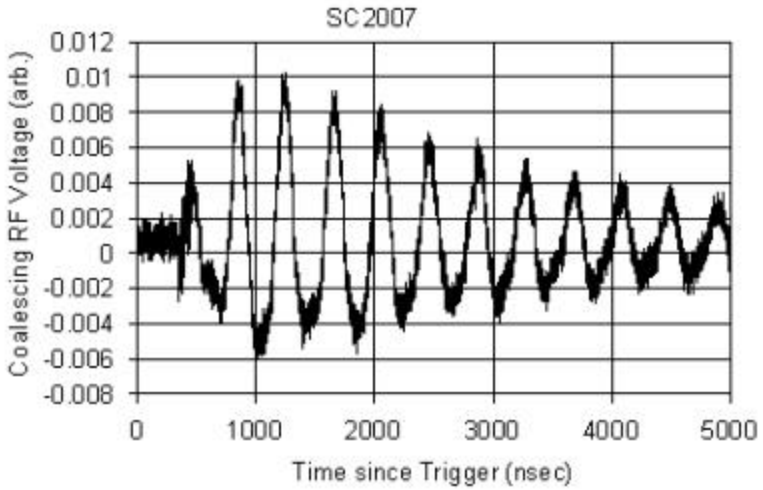
All with only 500V Arbitrary Waveform in MI

2nd Test in Main Injector



- Attempt at 2-Batch to 1-batch compression
- Dead RF Station made debunching impossible
- Re-try when Recycler LLRF available again

2.5 MHZ Transient Beam Loading Waveforms (GPJ)

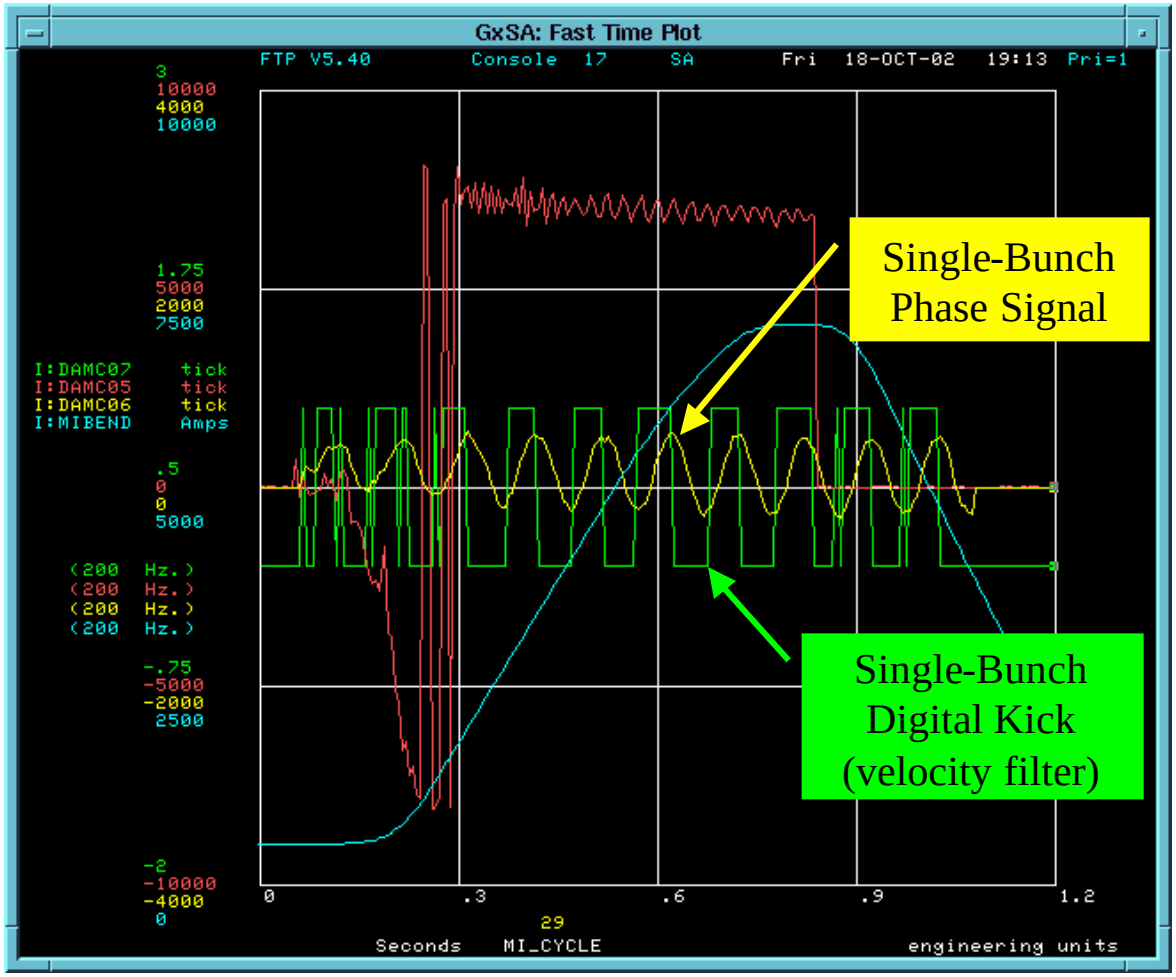


- Adiabatic Coalescing requires 200~500V
- Easy to generate with broadband system
- 2.5MHz Transient Beam Loading Voltages larger

✍ Reinstall Cavity shorts on 2.5 MHz cavities (Jan.)

MI Longitudinal Damper Kick Calculated in FPGA Firmware

(Ashmanskas, Foster)



MI Hardware Tasks

- Dedicated Broadband System in MI
  - Green Bomb & spare RR amp
  - Switch to Damper amps and cavities long term
  - Need dedicated Arbitrary Waveform module
- Cavity Shorts on 53 MHz cavities (installed)
- Cavity shorts on 2.5 MHz cavities (Jan.)
- LLRF work for Debunching/paraphasing
- Damper able to control Coupled-Bunch oscillations during debunching?

The Big Questions

- How will the Main Injector react to higher beam currents? ✍ *Find Out Soon*
- How Much Arbitrary Waveform Voltage will be needed? ✍ *Are Damper Amps OK?*
- How Efficient will Recapture and acceleration be? ✍ *NUMI Losses*
- What will the final longitudinal emittance be? ✍ *Pbar Production*